Design of Storm Sewer Pipe

Originally Issued: 12-01-95
Revised: 06-18-04

This section discusses the last major step in designing a storm sewer system. In this step, the designer determines pipe length, pipe size, and the depths of intakes and utility accesses. These quantities can be determined only after deciding the intake and access locations, as described in the previous sections.

The design of each storm sewer system assumes one of the following types of hydraulic flow:

- Full pipes where the water is under pressure (pressure flow), or
- Partially full pipes where the water is not under pressure.

Most urban projects in Iowa are designed assuming the majority of the pipes will be partially full and only a few pipes will be near or at capacity. In designs with partially full pipes, the designer uses Design Worksheet 104-5 (sample shown in Figure 1). The process for completing the worksheet is discussed in this section. This section also discusses pressure flow situations, but only those situations where pressure flow occurs for one or just a few pipes. Finally, the section discusses checking a system for major (100-year) storms. Samples of typical design problems for each situation are provided at the end of the section.

Partially Full Pipes and Design Worksheet 104-5

Worksheet 104-5 is set up for the design of a storm sewer that flows partially full during the design storm (the design storm is that storm which is expected only once during the recurrence interval). The worksheet is used in a fashion similar to how the pavement drainage design worksheet (in Section 4A-7) was used. However, information in the first seventeen columns of Worksheet 104-5 can be transferred directly to the appropriate project tabulation.

Intakes and utility accesses are listed by number in Column 1 and information is given about the intake or access in subsequent columns (through Column 6). Columns 7 through 17 are used to describe the pipes that run between these intakes and accesses. Later columns of the worksheet are used to help calculate much of the information in Columns 1 through 17. The following descriptions of each column's contents will assist the designer in completing the worksheet:

Column 1: The number of the intake or utility access. This number should be the same as the number of the drainage area. If a utility access does not have a drainage area number, an unused number should be assigned.

Column 2: The location (station and distance left or right) of intakes and utility accesses. See *Standard Road Plans* for the location points on intakes and utility accesses. For example, the location of the RA-40 intake is the middle of the intake at the back of the curb.

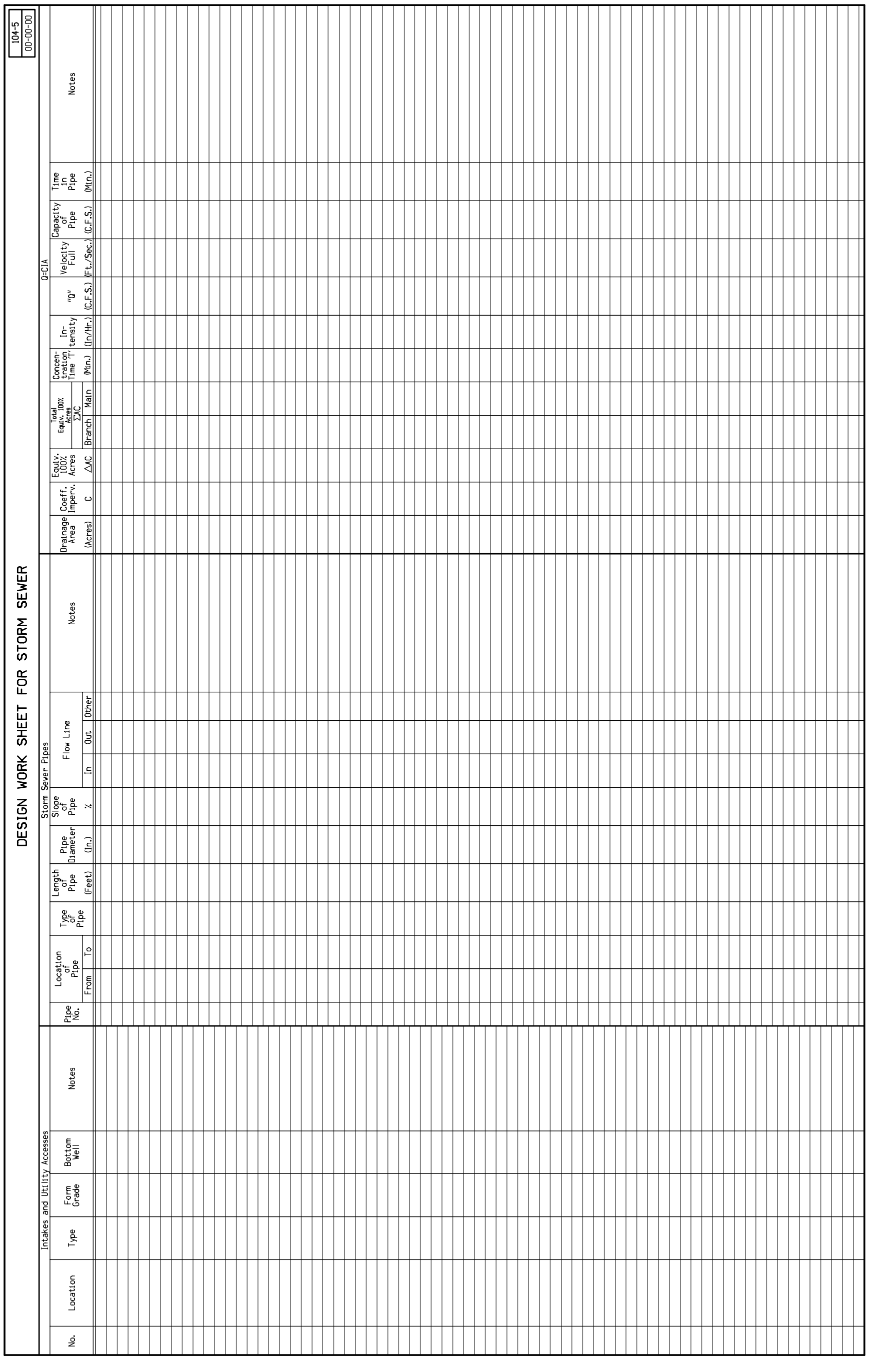

Figure 1: Sample of design worksheet 104-5 for storm sewer.

Column 3: The type of intake or utility access. See Section 4A-6 to determine the type (size) of the intake. Determine the type of utility access based on:

- Location (vehicular traffic or no vehicular traffic)
- Depth
- Size of intercepting storm sewer pipe

See Section 4A-3 for more information about choosing intake or utility accesses.

Column 4: The form (or gutter) grade. Determine from profile grades, staking sheets, or cross sections (see *Standard Road Plans).*

Column 5: The bottom of the well. This elevation is the top of the concrete slab base. Determine the bottom of the well by whichever of the following methods results in the lowest elevation:

- Determine the minimum acceptable depth of the intake or access by first checking in *Standard Road Plans* for that minimum depth (for the appropriate intake or access) and then subtracting the depth (approximately 4.0 feet or 1.2 meters) from the form grade (Column 4).
- Determine the intake or access depth needed for correct placement of the outlet pipe (pipe containing water flowing out of the intake or access). To do this, first subtract the thickness of the outlet pipe from the flow line elevation at the outlet pipe's inlet (see Figure 2). In most cases, the designer will need to wait until Column 14 on the worksheet ("flow line in") has been completed before completing this column. The thickness of the pipe is found on Standard Road Plan RF-1 (and in Table 1 of this section) using the pipe's type and diameter (Columns 10 and 12).

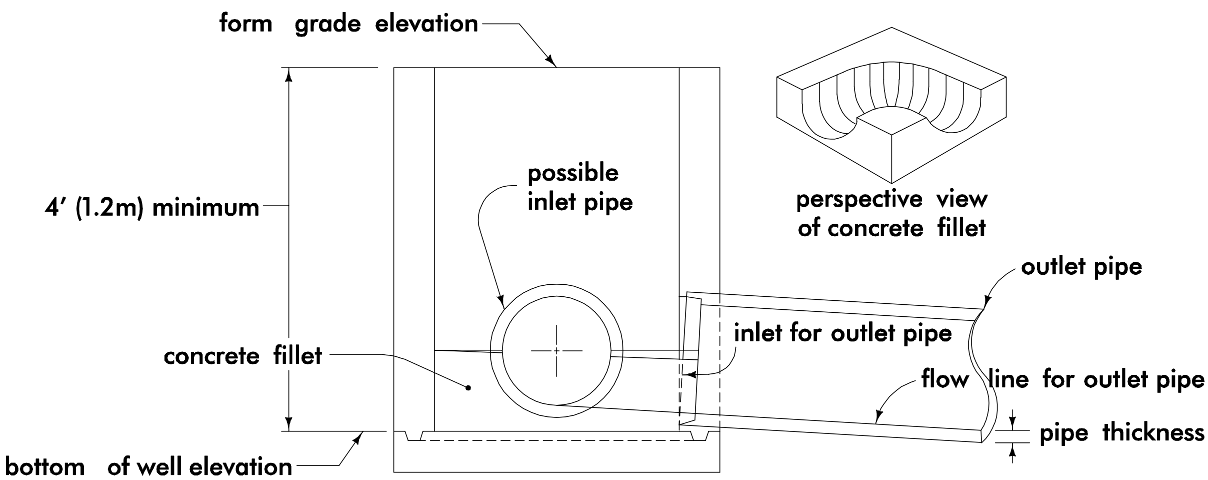

Figure 2: Depth of intake or utility access.

Typically, a concrete fillet is placed at the bottom of the well. Some cities, however, prefer to leave the concrete fillet out, creating a sump which allows the well to trap silt. The designer should check with the city and delete fillets when required. If no fillet is needed, then it needs to be indicated in the project tabulation (i.e., Tab 104-5A, notes column).

Column 6: The number used to identify any special notes or instructions for the intake or utility access. Write the notes in the appropriate place below the tabulations.

Starting with Column 7, the worksheet is used to determine the pipes between the intakes and accesses listed in Columns 1 through 6.

Column 7: The pipe number (P-1, P-2, etc.). The pipe number should normally be the same as the intake or utility access it is draining. For example, the pipe that water flows into from Intake 2 would be called P-2. In some cases, more than one pipe must be associated with a single intake, and the numbering system must be supplemented with letters (P-2A, P-2B, etc.). See Section 4A-3 for more details.

Column 8: The location of the upstream end of the pipe. List the number of the intake or utility access upstream from the pipe ("from").

Column 9: The location of the downstream end of the pipe. List the number of the intake or utility access downstream from the pipe ("to"). If the pipe is identified by other than an intake or a utility access number, use a note in Column 17 to give a description and location (e.g., Outlet pipe into the side of RCB at Sta. 1+00, 20′ Rt).

Column 10: The strength (or class) of pipe used. Use 2000D pipe (100D pipe if metric) under roadways and 1500D pipe (75D pipe if metric) under shoulders. If the storm sewer is 9 feet (2.7 meters) or more under the pavement, see Standard Road Plans RF-32 and RF-33. A stronger pipe will be required under a railroad, especially if jacking the pipe is required. Check with the railroad to determine if they have special requirements. This contact may be made through the Office of Rail Transportation of the Iowa DOT. Table 1 shows the thickness of the pipe walls for each class at a variety of diameters.

Table 1: Thickness of pipe walls.

English			metric		
diameter of pipe (in)	2000D (ft)	1500D (ft)	diameter of pipe (mm)	100D (mm)	75D (mm)
15	0.19	0.17	375	57	51
18	0.21	0.19	450	64	57
21	0.23	0.21	525	70	64
24	0.25	0.22	600	76	67
27	0.27	0.23	675	83	70
30	0.29	0.25	750	89	76
33	0.31	0.27	825	95	83
36	0.33	0.28	900	102	86
42	0.38	0.31	1050	114	95
48	0.42	0.35	1200	127	108
54	0.46	0.39	1350	140	117
60	0.50	0.42	1500	152	127
66	0.54	0.46	1650	165	140
72	0.58	0.50	1800	178	152
84	0.67	0.58	2100	203	178

Column 11: The length of the storm sewer pipe (measured in feet or meters). The length of a storm sewer pipe is considered the horizontal distance from the inside of the upstream intake (or access) wall to the inside of the downstream intake (or access) wall (measured to the next whole foot or nearest tenth of a meter). So if the distance is 17.4 feet, use 18 feet: if the distance is 5.31 meters, use 5.3 meters. When letdown structures (i.e., Typical 1401 or 1501) are used, calculate the exact distance, based on the slope of the pipe (Column 13). Round length to the nearest foot or tenth of a meter and adjust elbows and flow lines accordingly. If concrete pipe and CMP (corrugated metal pipe) are used on the same run, tabulate them on separate lines on the tabulation form.

For Columns 12 and 13, make initial estimates of the pipe's diameter and slope as described below. However, the final decisions on these dimensions must wait until the discharge (Q) flowing through the pipe has been calculated in Column 25.

Column 12: The diameter of the storm sewer pipe (measured in inches or millimeters). Try the smallest possible diameter as an initial estimate. The minimum diameter pipe used by the Iowa DOT is 15 inches (375 millimeters). However, do not decrease the size of pipe as you move downstream. This would create a possible choke point where the pipe could get plugged.

On interstate and freeway projects, the FHWA requires a minimum of 24-inch (600-millimeter) diameter pipes.

Column 13: The slope of the storm sewer pipe. The slope should closely parallel the proposed contour of the ground. Especially on long runs, a grade that is too flat or too steep will either not have enough cover or will be too deep in the ground. Try the average slope of the ground as an initial estimate.

Column 14: The flow line (inside bottom of the pipe) at the upstream end of the pipe. This is the outlet elevation for the intake or access or, alternatively, the inlet elevation of the pipe. This elevation must be lower than the flow lines of any pipes entering the intake or access to avoid trapping water. To determine the flow line, check all flow lines and diameters for pipes entering the intake or access. The drop in elevation through the intake must be enough to maintain velocity and account for head losses. Ideally, the hydraulic grade line (top of the water when the pipe is partially full) should maintain a smooth slope and constant velocity throughout the storm sewer system. This will eliminate pressure flow, low velocities, water sitting in pipes, and silting.

If the outgoing pipe is the same diameter as the incoming pipes, drop the flow line at least 0.10 feet (0.03 meters) when passing through the intake or access. If the diameter of the outgoing pipe is larger than those of the incoming pipes, align the tops of the pipes, as shown in Figure 3. This will result in a small drop in the hydraulic gradient through the intake or access. On very flat grades, where aligning the tops of the pipes will make the slope of the downstream pipe too small to maintain the appropriate water velocity, try aligning lines that represent 80% of the pipes' diameters (0.8d). This is also shown in Figure 3. Keep in mind that these are the minimum elevation drops that can be used when elevation is a problem. On steeper grades, it may be necessary to make much larger drops in elevation through intakes or accesses to reduce the slopes of pipes and thereby keep the water's velocity under 15 ft./sec (4.5 m/sec.).

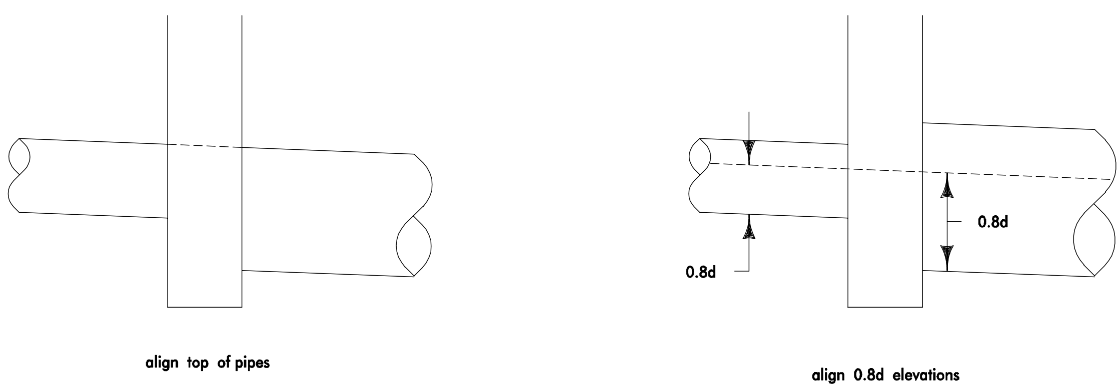

Figure 3: Pipe alignment.

Column 15: The flow line at the downstream end of the storm sewer pipe. This elevation is calculated by multiplying Column 11 (length) by Column 13 (slope) and subtracting the result from Column 14 (flow line in). Check the elevation of the next intake to make sure the pipe is not too shallow (at least 1 foot or 300 millimeters of cover is required).

Column 16: Other items in the system. Use this column when elbows or breaks in grade are used in storm sewer pipes. One example is a letdown structure. Explain the need for extra flow lines with a note in Column 17. Pipe profile sheets will also be helpful in showing such changes in elevation.

Column 17: The number used to identify any special notes or instructions for the storm sewer pipes. Write the notes in the appropriate place below the tabulations.

Beginning with Column 18, the rest of the chart is used to determine characteristics of the water flowing in the pipe. Many of these characteristics have already been determined using the Rational Method in Section 4A-4.

Column 18: The drainage area (measured in acres) which drains into the intake immediately upstream from the pipe (see Column 8, "From"). If a utility access that does not function as an intake is immediately upstream (no runoff is entering the storm sewer at this point), this column would be left blank (or 0.0 would be entered).

Column 19: The value of C (the runoff coefficient) assigned to the drainage area in Column 18. To simplify calculations, assign a C to the entire drainage area for the storm sewer system. See Section 4A-4 for more details.

Column 20: The equivalent acres (AC) for the drainage area in Column 18. Multiply Column 18 and Column 19.

Column 21: The equivalent acres from all branches that drain into the current pipe. Add all ACs from Column 20 that are upstream from this pipe.

Column 22: The total equivalent acres (AC), including AC from the current pipe.
Column 22 = Column 20 + Column 21.

Column 23: The time of concentration (T) for the pipe. This is the total time it takes for water to run from the most distant point in the pipe's drainage area (in terms of flow time) to the location of the pipe. This time includes T_c (overland flow), the time in gutters or drainage ditches, and the time in the pipes upstream from this pipe. At each intake and pipe junction, compare the time of concentration for the intake to the time of concentration for the upstream pipes at that point. Use whichever is the greatest. At the next intake or pipe junction downstream, add the time of water in this pipe and repeat the process. Repeat for each pipe in the system.

Column 24: The rainfall intensity, I. Using the time of concentration calculated in Column 23 as the duration and using the recurrence interval as the frequency, find the intensity (I) in Table 5 of Section 4A-4. See Section 4A-1 or Section 4A-4 for the appropriate recurrence interval for each situation.

Column 25: The rate of flow, Q, measured in cfs or m^3/s. Multiply Column 22 (AC) by Column 24 (I). If using metric units, divide by K, where K=360.

Now that the rate of flow in the pipe is known, use Figure 4 (Figure 5 if using metric units) to check the initial estimates of pipe diameter and slope (Columns 12 and 13) to see if the pipe's capacity and the water's velocity are appropriate. Often this is a trial and error process, which is repeated until acceptable values of all quantities are found.

Column 26: The velocity of water in the pipe. Using Figure 4 or 5, find the water's velocity (diagonals from top left to bottom right) from the pipe's diameter (diagonals from bottom left to top right) and slope (horizontal lines). Adjust the diameter and slope until a velocity greater than 3 ft./sec. (0.9 m/sec.) and less than 15 ft./sec (4.5 m/sec.) is achieved.

Column 27: The capacity of the storm sewer pipe. Again using the pipe's diameter and slope in Figure 4 or 5, find the capacity (vertical lines). If the capacity is less than the rate of flow (Q) determined in Column 25, adjust the slope and pipe size until the capacity is greater than Q. Note that the adjustments must still leave the water's velocity within the parameters mentioned in Column 26.

Column 28: The amount of time the water is in the pipe (measured in minutes). Determine this time by dividing Column 11 (the length of the pipe) by Column 26 (the velocity) and then dividing the result by 60 to get the time in minutes.

After completing Column 28 for every pipe in the storm sewer system, Design Worksheet 104-5 should be finished. A sample problem illustrating this procedure is provided later in this section.

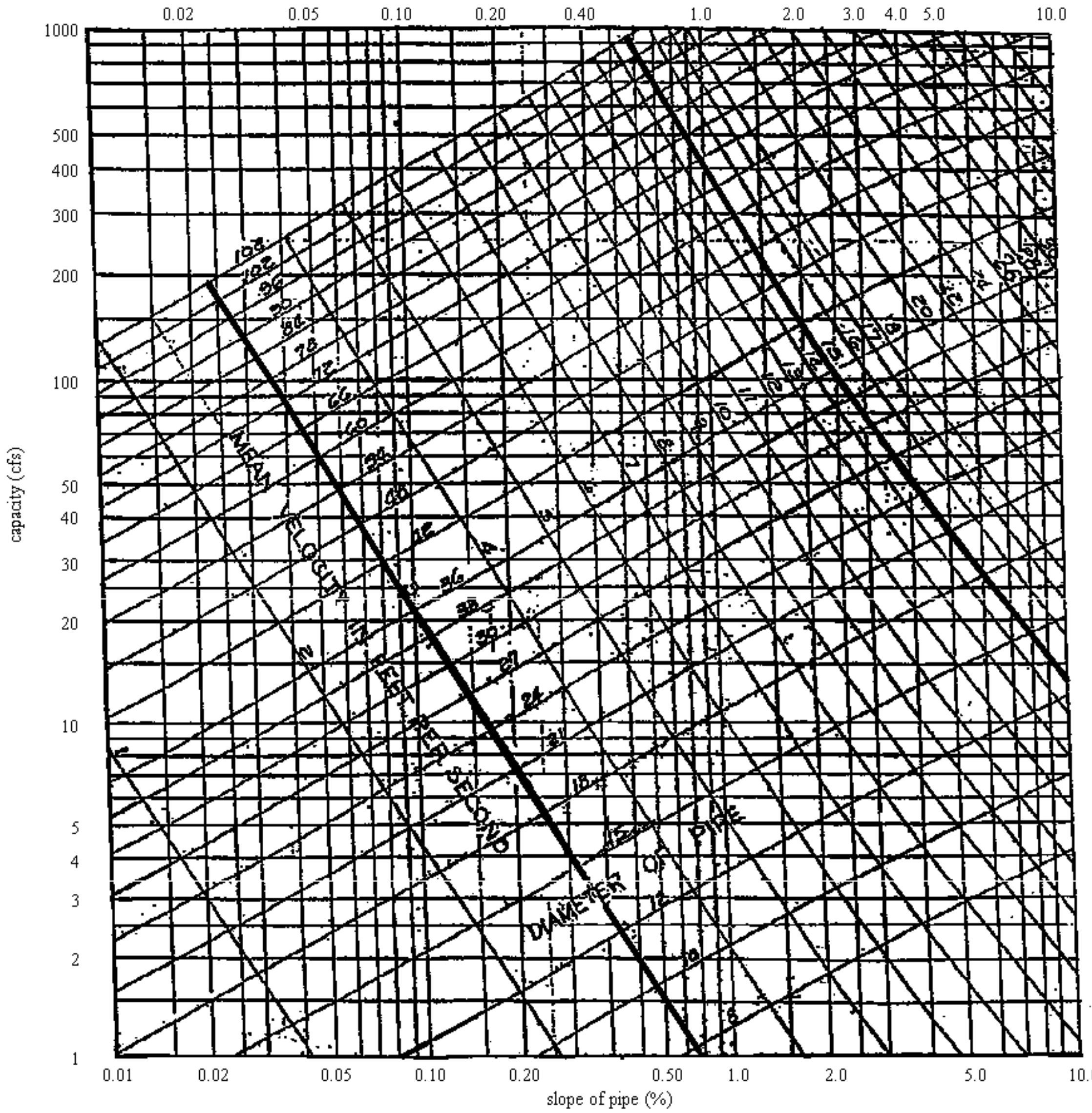

Figure 4: Capacity of circular storm sewers (English units).

Figure 4 was generated using:

$$Q = VA$$

$$= \left(\frac{1.486}{n}\right)\left(R^{0.67}\right)\left(S^{0.5}\right)A$$

where:

- Q = capacity (discharge if pipe is full)
- V = velocity
- A = cross sectional area of the pipe
- R = hydraulic radius = $\frac{\text{cross sectional area of flow}}{\text{wetted perimeter}}$
- S = slope of pipe
- n = Manning's coefficient = 0.013

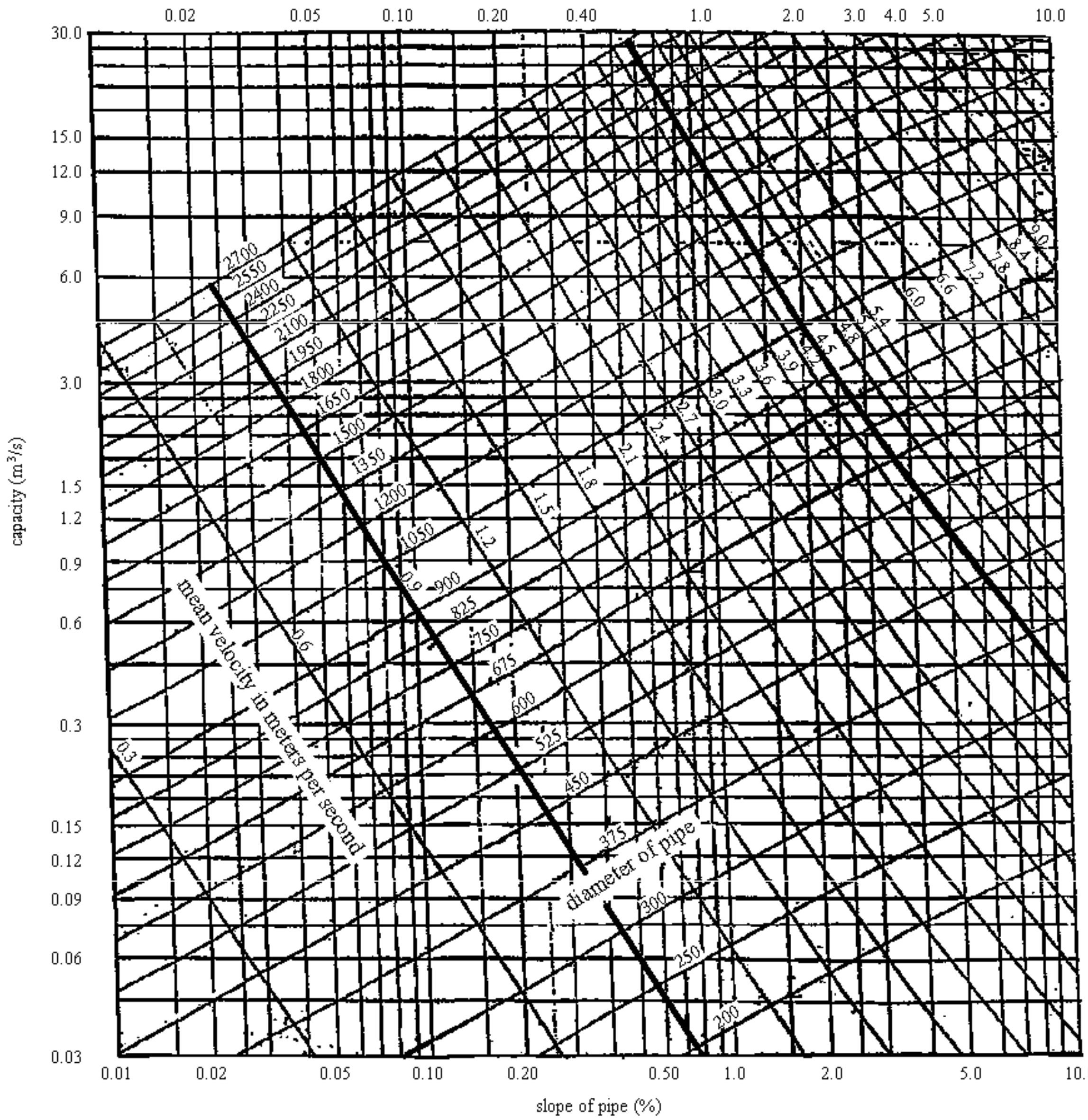

Figure 5: Capacity of circular storm sewers (metric units).

Figure 5 was generated using English units and converting to metric.

Pressure Flow Design

Pressure flow designs generally require many more calculations and allow much less room for error than non-pressure designs. Designers should therefore try to avoid pressure flows. Nonetheless, in the following situations, it may be necessary to consider pressure flow for parts of the storm sewer system:

- When the locations of other utilities restrict the size or location of a storm sewer pipe
- When pressure flow for a short distance is more economical than maintaining a partially full pipe
- When checking the system for major (100-year) storms

In any of these cases, it is important to understand the dynamics of pressure flow presented in this section. However, if water backs up for several pipes in a row during a design storm (causing the hydraulic grade line to be higher than the tops of the pipes), a pressure flow design will be necessary for the total system. If this is the case, see other design manuals for more information on the design of pressure flow storm sewer systems.

When a pressure flow situation arises, the two variables affected by the pressure are the water's velocity and the capacity of the pipe. These variables are affected because rather than using the slope of the actual pipe to determine them (in Figure 4), the designer instead uses the hydraulic gradient (the slope of the hydraulic grade line, shown in Figure 6 below).

The hydraulic grade line coincides with the water's surface in open channel flow and partially full pipes. However, in pressure flow, the hydraulic grade line represents the height to which water will rise in a piezometer at any point along a pipe. In storm sewer design, assume that intake wells act as piezometers (see Figure 6), showing pressure at the points in the storm sewer system where they are located. The pressure the intake wells measure is the pressure available to force the water through the storm sewer pipe.

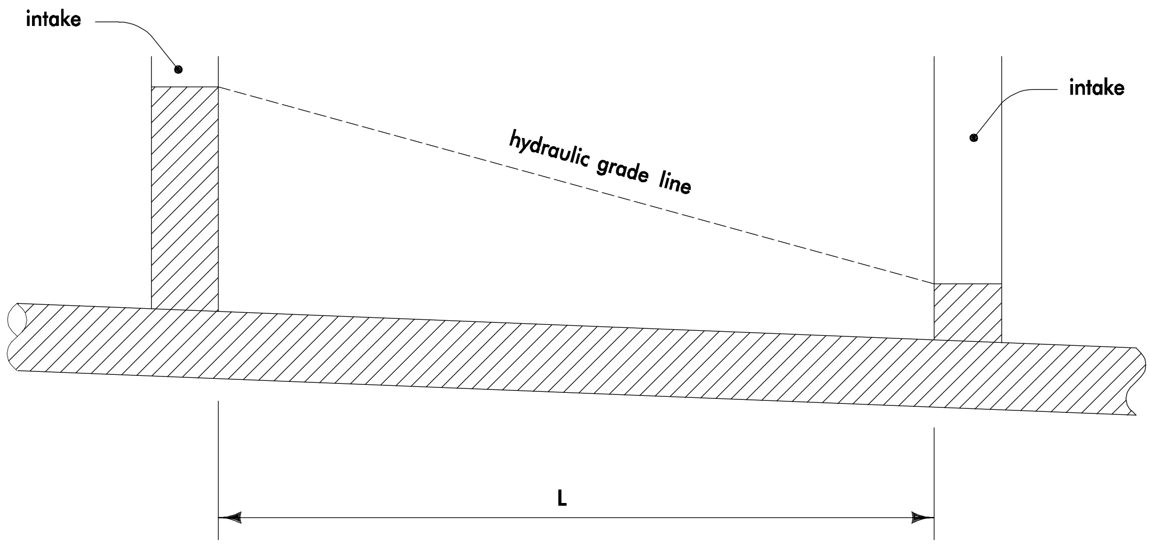

Figure 6: Intakes acting as piezometers.

To calculate the hydraulic gradient, subtract the water's elevation (measured from the baseline) in the downstream intake well from its elevation in the upstream intake well. Then divide by the length of the pipe:

$$\text{hydraulic gradient} = \frac{\text{elev}_{\text{upstream}} - \text{elev}_{\text{downstream}}}{\text{length}}$$

Using the hydraulic gradient in place of the pipe's slope, the designer can then determine the water's velocity and the pipe's capacity using Figure 4. The water's velocity for a design storm should be within the limits discussed earlier (3–15 ft./sec. or 0.9–4.5 m/sec.). The pipe's capacity must be able to handle the design discharge (Q) without overflowing the intakes, and thus causing water to run out into the gutter.

Two sample problems illustrating these calculations for pressure flow situations are provided later in this section.

Check for Major Storms

One of the last procedures in designing a storm sewer system is the major storm check. Most structures in the system are designed for relatively minor storms with frequencies of ten years or less. However, the designer must also consider how the system will function when major storms occur (recurrence intervals of 50 or 100 years). While we don't expect the storm sewer to function normally during a major storm, it should function well enough to prevent serious property damage and dangerous situations for pedestrians and motorists.

The designer uses a 100-year recurrence interval to check for major storms. Three overriding concerns dominate the major storm check:

- Ponding on primary highways may not exceed 1 foot (0.3 meters).
- Neither residential dwellings nor public, commercial, or industrial buildings may be inundated at the ground line, unless they are flood-proofed.
- Large flows of water may not be created in areas where such flows are particularly hazardous.

To avoid these situations, the designer may need to install drainage structures not called for by the system's normal recurrence interval.

When checking for major storms, the designer tries to decide how the excess water will be stored and how it will reach the storm sewer's outlet (river, lake, etc). Factors influencing these decisions include:

- Ponding at low points
- How much water bypasses intakes
- Capacity of the storm sewer (under pressure flow)
- Overland flow of water

One of the biggest problems for major storms is ponding in low-lying areas. This is because water that cannot get into the storm sewer tends to flow in roadways and over land into such areas. Often, the capacities of individual intakes or of the entire storm sewer system must therefore be increased in low-lying areas to accommodate major storms. When checking the capacities of these intakes and storm sewer, the designer assumes that the intake is 1 foot under water since 1 foot (0.3 meters) is the greatest depth permitted on primary highways. Figure 6 in Section 4A-6 is used to calculate the water depth since any intake would be operating as an orifice in this situation. The designer can also assume that most pipes in the storm sewer are under pressure flow. To determine the storm sewer pipe's capacity, calculate the hydraulic gradient from the intake that is 1 foot (0.3 meters) under water to the outlet (see Pressure Flow Sample Problem #2 later in this section).

Be certain to decide whether water will flow over land before it gets unacceptably deep. Check the capacity of the outlet storm sewer when the intake is under water to determine how much water will be carried by the storm sewer when the intake is submerged. When water flows over land, use open channel flow to determine the depth of water in drainage channels, ditches, or low areas.

The storm sewer's outlet pipe may also be under water during major storms. High-water elevations for rivers and creeks can be obtained from the Survey or Preliminary Bridge Sections to allow the capacity of the outlet to be calculated when it is submerged. If the outlet goes through a levee, then a flood gate or flap gate may be necessary. If the gate is closed, storage must be available to hold water until it can be pumped or until the gate can be opened.

Other methods of checking for major storms are available. Computer programs have been developed and are available for use. One such program is the HYDRAIN computer system. HYDRAIN is a good way to check for major storms because it will alert the designer when pressure flow occurs. It can also be used to design a system for pressure flow under normal design conditions. Use the HYDRA program in the HYDRAIN user manual.

A sample problem for a major storm check is provided later in this section. Forms for pressure flow design and examples of such designs can also be found in other design manuals. Form 104-5 in this manual was developed for partially full designs only. Do not use it for pressure flow, except over short distances or in the major storm check.

Intake #1: A = 0.50 acres
T_c = 8.2 minutes
C = 0.3
S_x = 0.03
S_L = 0.01

Intake #2: A = 0.90 acres
T_c = 10 minutes
C = 0.4
S_x = 0.03
S_L = 0.006

Intake #3: A = 0.45 acres
T_c = 10 minutes
C = 0.5
S_x = 0.03
S_L = 0.04

Intake #4: A = 0.40 acres (water from south)
T_c = 10 minutes
C = 0.3
S_x = 0.03

A = 0.40 acres (water from north)
T_c = 10 minutes
C = 0.3
S_x = 0.03

After solving the problem in Section 4A-7, we now also know the following information. The form (gutter) grade was determined from the profile grade, the staking sheets, and the cross sections for the project.

Intake Number	Intake Type	Intake Location	Form Grade
1	RA-40	Sta. 1+00, 15.5′ Lt	200.00
2	RA-40	Sta. 3+50, 15.5′ Lt	198.12
3	RA-43	Sta. 6+25, 15.5′ Lt	192.46
4	RA-43	Sta. 8+00, 15.5′ Lt	187.78

Additionally, an 8-inch diameter water main is located at Station 7+90. The top of the pipe has an elevation of 185.60.

Intake #1 and Pipe P-1

Begin the problem by filling out information we already know about the first intake and pipe.

Column 1: Intake # = 1

Column 2: Location = 1+00, 15.5′ Lt

Column 3: Type = RA-40

Column 4: Form Grade = 200.00

Column 5: For this intake, assume that the minimum intake depth is well below the flow line of the pipe. Thus:

$$\text{bottom of well} = \text{form grade} - 4.0 = 196.00$$

Column 6: There are no special notes for this intake.

Columns 7,8, & 9: We know from our preliminary design that pipe P-1 is between Intakes 1 and 2.

Column 10: For the purpose of this example, assume that this pipe is not under a roadway and that it is buried less than 9 feet underground. Thus, use a 1500D pipe.

Column 11: Calculate the length of pipe P-1 by subtracting the location of Intake 1 (Station 1+00) from the location of Intake 2 (Station 3+50). Then subtract the inside dimensions of the intakes (location point to inside dimension of wall).

$$[(3+50)-(1+00)]-(2\text{ ft}+2\text{ ft})=250\text{ ft}-4\text{ ft}=246\text{ ft}$$

Column 12: 15-inch storm sewer pipe is the minimum size allowable, so use 15 inches as a first estimate.

Column 13: Estimate a slope for the pipe by calculating the average ground slope between intakes. Subtract the form grades for the intakes (Column 4) and divide by the length of the pipe (Column 11) to get the average ground slope:

$$\frac{200.00-198.12}{246}=0.76\%$$

Use a slope of 0.8% for pipe 1.

Column 14:

$$\begin{aligned}\text{Flow line in} &= \text{bottom of the well}+\text{pipe thickness}\\ &=196.00\text{ (from Column 5)}+0.17\text{ (from Table 1)}\\ &=196.17\end{aligned}$$

Column 15:

$$\begin{aligned}\text{Flow line out} &= \text{flow line in}-(\text{length of pipe}\times\text{slope})\\ &=196.17-(246\times 0.008)\\ &=194.20\end{aligned}$$

Column 16 & 17: No special situations exist with this pipe which call for the use of these columns.

Column 18: Drainage area (A) = 0.5 acres

For Column 19, the designer may wish to use the runoff coefficient (C) calculated for the individual intake's drainage area. However, in this case, calculate an average value of C for all four intakes (using the method described in Section 4A-4). This method will result in the same overall value for Q, but it may throw off Q for the individual intakes.

Column 19:

$$\text{Ave. C Value} = \frac{(0.5\times 0.3)+(0.9\times 0.4)+(0.45\times 0.5)+(0.8\times 0.3)}{0.5+0.9+0.45+0.8}$$

$$= \frac{0.975}{2.65} = 0.367 \text{ (use 0.4)}$$

Column 20: $\Delta AC = 0.5 \times 0.4 = 0.20$

Column 21: Since this is the first intake in the system, the equivalent acres for previous intakes is zero.

Column 22: $\Sigma AC = \Delta AC = 0.20$

Column 23: $T = T_c = 8.2$ minutes (from Figure 1 Section 4A-7)

Column 24: Calculate intensity (I) as shown in Section 4A-4. From Table 5 of Section 4A-4 and using a recurrence interval of 10 years with a storm duration (T_c) of 8.2 minutes and interpolating, I = 0.83in/8.2min.×60 min/h = 6.1 in./hr.

DESIGN WORK SHEET FOR STORM SEWER

104-5
00-00-00

Intakes and Utility Accesses

1 No.	2 Location	3 Type	4 Form Grade	5 Bottom Well	6 Notes
1	1+00, 15.5' Lt.	RA-40	200.00	196.00	
2	3+50, 15.5' Lt.	RA-40	198.12	193.91	
3	6+25, 15.5' Lt.	RA-43	192.46	188.18	
4	8+00, 15.5' Lt.	RA-43	187.78	182.63	

Storm Sewer Pipes

7 Pipe No.	Location of Pipe 8 From	9 To	10 Type of Pipe	11 Length of Pipe (Feet)	12 Pipe Diameter (In.)	13 Slope of Pipe %	Flow Line 14 In	15 Out	16 Other	17 Notes
P-1	1	2	1500D	246	15	0.80	196.17	194.20		
P-2	2	3	2000D	269	15	2.10	194.10	188.45		
P-3	3	4	1500D	167	15	3.17	188.35	183.05		Existing 8" water main at Sta. 7+90, elevation of 185.60.
P-4	4	Outlet	1500D	100	15	0.55 0.40	182.95 182.80	182.40		Outlet at existing utility access, Sta. 8+25, 117' Lt., elevation of 182.40.

Q=CIA

Pipe No.	18 Drainage Area (Acres)	19 Coeff. Imperv. C	20 Equiv. 100% Acres ΔAC	Total Equiv. 100% Acres ΣAC 21 Branch	22 Main	23 Concentration Time "T" (Min.)	24 Intensity "I" (In/Hr.)	25 "Q" (C.F.S.)	26 Velocity Full (Ft./Sec.)	27 Capacity of Pipe (C.F.S.)	28 Time in Pipe (Min.)	29 Notes
P-1	0.50	0.4	0.20	-	0.20	8.2	6.1	1.22	4.8	6.0	0.9	
P-2	0.90	0.4	0.36	0.20	0.56	10.0	5.9	3.30	7.8	9.5	0.6	
P-3	0.45	0.4	0.18	0.56	0.74	10.6	5.7	4.29	9.8	11.5	0.3	
P-4	0.80	0.4	0.32	0.74	1.06	10.9	5.7	6.04	4.5 4.2	5.5 7.5	0.4 0.4	Too small. OK

Figure 7: Completed design worksheet for sample problem.

Column 25: $Q = CIA = 0.20 \times 6.1 = 1.22$ cfs

Now check the estimates of the pipe's diameter and slope by using Figure 4 to determine the water velocity and pipe capacity.

Column 26: Velocity = 4.8 ft./sec.

Column 27: Capacity = 6 cfs

Since the capacity is greater than Q and the velocity is between 3 and 15 ft./sec., the estimates of diameter and slope are acceptable. Consequently, the estimates for the pipe's slope and diameter (Columns 12 and 13) will be used.

Column 28: Calculate the time in the pipe (in minutes):

$$\text{Time (in min.)} = \frac{\text{Length}}{(60)(\text{velocity})}$$

$$\text{Time (in min.)} = \frac{246}{(60)(4.8)} = 0.9 \text{ minutes}$$

Intake #2 and Pipe P-2

Next, repeat the calculations for Intake and Pipe P-2. For the remaining intakes and pipes, describe only those entries where confusion might arise because the procedure is different than for #1.

Columns 1–4: See procedure for Intake #1.

Column 5: For this intake, assume that the downstream pipe's inlet is lower than four feet. Wait until the pipe's flow line is determined before trying to calculate Column 5.

Columns 6–9: See procedure for Intake/Pipe #1.

Column 10: Pipe #2 (P-2) runs under a street. Therefore use a 2000D pipe.

Column 11: See procedure for Pipe #1 (P-1).

Column 12: Estimate pipe's diameter at 15 inches since P-1 was 15 inches.

Column 13: See procedure for P-1.

Column 14: The flow line of P-1 at Intake 2 is 194.20 feet (Column 15 for P-1). Assuming a drop of 0.10 feet through Intake 2, the flow line in for P-2 will be 194.10 feet.

Columns 15–17: See procedure for P-1.

Now that the flow line has been calculated, return to Column 5 and determine the bottom of the well for Intake #2.

$$\begin{aligned}\text{bottom of well} &= \text{flow line in (P-1, Column 14)} - \text{thickness of pipe}\\ &= 194.10 - 0.19\\ &= 193.91 \text{ feet}\\ \text{depth of intake} &= 198.12 \text{ (form grade)} - 193.91 \text{ (bottom of well)}\\ &= 4.21 \text{ feet}\end{aligned}$$

This is greater than the 4-foot minimum depth. 193.91 is therefore the correct value.

Column 18–20: See procedure for P-1. C (= 0.4) in Column 19 is the average for all four intakes.

Column 21: Equivalent acres = ΣAC (for P-1)

Column 22:

$$\begin{aligned}\Sigma AC &= \Sigma AC \text{ (for P-1)} + \Delta AC \text{ (for P-2)}\\ &= 0.20 + 0.36 = 0.56\end{aligned}$$

Column 23: T (P-2) = T_c(Intake #2) or T_c (Intake #1) + time in P-1, whichever is longer.

$$T_c\ (\text{Intake \#2}) = 10\ \text{minutes}$$
$$T_c (\text{Intake \#1}) = 8.2\ \text{minutes}$$
$$\text{Time in P-1} (\text{Column 18}) = 0.9\ \text{minutes}$$
$$8.2\ \text{minutes} + 0.9\ \text{minutes} = 9.1\ \text{minutes}$$

Use the larger number, T (P-2) = 10 minutes.

Columns 24–28: See procedure for P-1.

Intake #3 and Pipe P-3

Repeat the calculations for Intake and Pipe 3.

Columns 1–9: See procedure for Intake/Pipe #2.

Column 10: P-3 is not under a roadway, and it is buried less than 9 feet underground. Thus, use a 1500D pipe.

Column 11: See procedure for P-2.

Column 12: Estimate pipe's diameter at 15 inches since P-2 was 15 inches.

Columns 13–14: The average slope of the ground = (192.46 - 187.78) / 167 = 2.8%. However, an 8-inch water main is located at Station 7+90, at an elevation of 185.60 (top of main). The presence of this main prevents the storm sewer pipe from having a 2.8% slope. Check to see whether the storm sewer should go over or under the water main:

1. Decide whether placing the storm sewer above the main will allow for the required 1 foot of cover. To do this, take the elevation of the top of the water main (185.60 ft.) and add the diameter of the storm sewer pipe (1.25 feet) and the thickness of the pipe's walls (2 × 0.17):

   Top of Storm Sewer = 185.60 + 1.25 + 2(0.17) = 187.19 feet

   Since the form grade at Station 8+00 is 187.78 due to the sag in the vertical curve, 1 foot of cover would not be maintained if the storm sewer were placed above the water main. The storm sewer must therefore be placed under the water main.

2. Since the storm sewer must go under the water main, determine the minimum elevation at which it can be placed. To do this, take the elevation of the 8-inch main's top (185.60 feet) and subtract 0.67 feet (the 8-inch diameter) and 0.10 feet (the thickness of the water main's walls). Then subtract 1.25 feet (the 15-inch diameter of the storm sewer) and 0.34 feet (the thickness of the pipe's walls):

$$\begin{aligned}\text{Storm sewer elevation} &= 185.60 - (0.67 + 0.10 + 1.25 + 0.34)\\ &= 183.24\ \text{feet}\end{aligned}$$

   This is the highest elevation at which the storm sewer can be placed at Station 7+90.

3. Using this maximum elevation, determine the slope of the pipe. The slope is the difference in elevation between the "flow line in" (Column 14) and the maximum elevation under the water main. The "flow line in" is calculated by subtracting 0.10 from the "flow line out" of P-2:

Flow line in = 188.45 – 0.10 = 188.35

Using this elevation, the slope of the pipe between Intake #3 and the water main can be determined:

Pipe length = [(7+90)-(6+25)] – 4 (from Intake #3) = 161 feet

$$\text{Slope} = \frac{(188.35 - 183.24)}{161} = 3.17\%$$

Column 15:

Flow line out = Column 14 – (Column 11 x Column 13)

= 188.35 – (167 x 3.17%) = 183.05

Columns 16–17: See procedure for P-2. Add in note to describe water main location and elevation.

Columns 18–20: See procedure for P-2.

Column 21: Equivalent acres = ΣAC (for P-2) = 0.56

Column 22: Add Column 20 (= 0.18) to Column 21 (= 0.56) to get ΣAC = 0.74

Column 23: T (P-3) = Tc (Intake #3) *or* Tc (Intake #2) + time in P-2, whichever is longer.

$$T_c(\text{Intake \#3}) = 10 \text{ minutes}$$
$$T_c(\text{Intake \#2}) + \text{time in P-2} = 10 + 0.6 = 10.6 \text{ minutes}$$
$$T = \text{the longer time} = 10.6 \text{ minutes}$$

Columns 24–28: See procedure for P-2.

Intake #4 and Pipe P-4

Repeat the calculations for Intake and Pipe #4. P-4 is different from the other pipes because the downstream end of the pipe is the storm sewer's outlet. The outlet's elevation is set at 182.40 feet. Consequently, the pipe's slope is constrained by the outlet's elevation, the downstream flow line of P-3, and the slope of the ground above. Clearly, when using Figure 4 for this pipe, the designer has little room to manipulate the slope and must therefore rely primarily on changing pipe size.

Columns 1–10: See procedure for Intake/Pipe #3.

Column 11: The outlet is located 25 feet forward and 101.5 feet to the left of Intake #4. Taking into account the inside dimensions of the intake and the dimensions of the outlet, a 100-foot pipe will be needed.

Column 12: Try a 15-inch storm sewer pipe.

Column 13: Calculate slope using the outlet elevation (182.40 feet) and the flow line in (182.95 feet):

$$\frac{182.95 - 182.40}{100} = 0.55\%$$

Column 14: Subtract 0.10 from Column 15 for P-3:

183.05 – 0.10 = 182.95 feet

Column 15: Outlet elevation is 182.40 feet.

Column 16: Leave blank.

Column 17: Add note to describe outlet location and elevation.

Columns 18–25: See procedure for P-2.

Columns 26–27: Use Figure 4 to try to find a capacity for a 15-inch storm sewer pipe that will result in an acceptable velocity (3–15 ft./sec.).

The maximum capacity for a 15-inch pipe is 5.5 cfs. Since Q is 6.04 cfs (Column 25), the 15-inch pipe is too small. Therefore try an 18-inch pipe in Column 12 and recalculate the quantities affected by this change.

Column 14: Find the difference in the diameters of P-3 and P-4 and subtract this difference from the flow line out for P-3:

$$183.05 - (1.50-1.25) = 182.80$$

Column 13: Calculate the new slope:

$$\frac{182.80 - 182.40}{100} = 0.40\%$$

Column 27: Using Figure 4, find the capacity for an 18-inch pipe on 0.40% slope to be 7.5 cfs. Use the 18-inch diameter pipe.

This has been a simple storm sewer design done in English units. The procedure is exactly the same for metric units. On most design problems, there are existing utilities, flat grades, clearance problems, shallow intakes, and other difficulties. Use sound engineering judgment in each of these cases to come up with a good design.

Pressure Flow Sample Problems

Sample Problem 1

Given: An existing storm sewer pipe (shown in Figure 7) is in good condition, and because of its location, could potentially be used in a new storm sewer. The relevant dimensions for the pipe are:

Length = 300 feet

Diameter = 24 inches

Slope = 1.0%

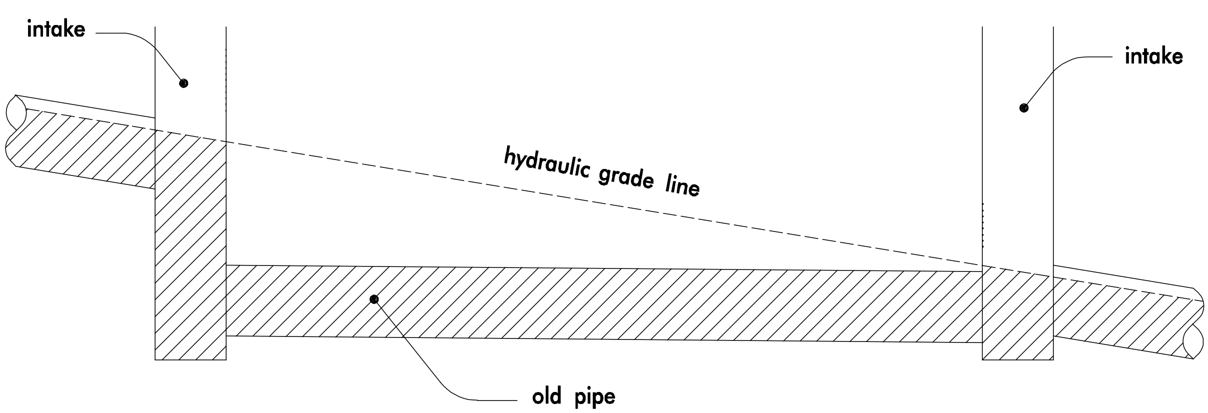

Figure 8: Old storm sewer pipe (Sample Problem 1).

Problem: Can the pipe actually be used in the new storm sewer, which has a design discharge of Q = 40 cfs at the upstream intake?

To decide whether the pipe can be used, first check its capacity and the velocity of the water when the pipe is less than full (no pressure).

1. Use the pipe's diameter and slope in Figure 4 to get a capacity of 24 cfs and a velocity of 7.3 ft./sec.

   The water's velocity is acceptable, but the partially full capacity is below the design discharge for the new storm sewer. Rather than discarding the pipe, check to see if it can handle the discharge under pressure flow.

2. Returning to Figure 4, use the required capacity (Q = 40 cfs) to determine that the needed hydraulic gradient (rather than slope) for a 24-inch pipe is 3.0%. Be certain that the water's velocity remains between 3 and 15 ft./sec.

3. Calculate the elevation of water that will need to back up in the upstream intake to create the needed hydraulic gradient.

   a. As Figure 7 shows, the water's elevation in the downstream intake will be at or below the top of the pipe (assuming the next pipe does not have pressure flow). Thus, use the top of the pipe as the water elevation in the downstream intake.
   b. Multiply the length of the pipe (300 feet) and the hydraulic gradient (3.0%) to get 9.0 feet. Add the 9.0 feet to the top of the pipe at the outlet of the downstream intake. This is the elevation to which the water in the upstream intake will rise to carry the 40 cfs. If this elevation is above the intake form grade, the pipe will not have the capacity to carry 40 cfs and therefore will need to be replaced.

The same procedure would be used for metric units.

Sample Problem 2

Given: The outlet of a storm sewer goes under water when checking the system for a major storm (the high water elevation for the river, lake, etc. can be determined from survey information or preliminary bridge plans). The relevant factors already determined for the system are:

Q (discharge at upstream intake) = 50 cfs

Pipe length = 300 feet

Elevation of upstream pipe's outlet = 17 feet

High water elevation = 16 feet

Problem: What diameter will the pipe need to be to keep water from backing up into the previous pipe upstream?

As shown in Figure 9, the elevations of all parts of the pipe are below the high water elevation for the river. The designer can therefore assume pressure flow in all parts of the pipe.

1. Find the hydraulic gradient for the pipe by first subtracting the high water elevation for the river from the elevation of the water emerging from the upstream pipe. Then, divide the difference in elevation by the length of the pipe.

$$\text{hydraulic gradient} = \frac{17\text{ ft} - 16\text{ ft}}{300\text{ ft}} = 0.0033 = 0.33\%$$

2. Using the hydraulic gradient as the slope in Figure 4, determine a pipe diameter that will be able to drain Q = 50 cfs. A 42-inch pipe will be needed. In choosing a pipe diameter, make certain that under pressure the water's velocity stays between 3 and 15 ft./sec. on the chart.

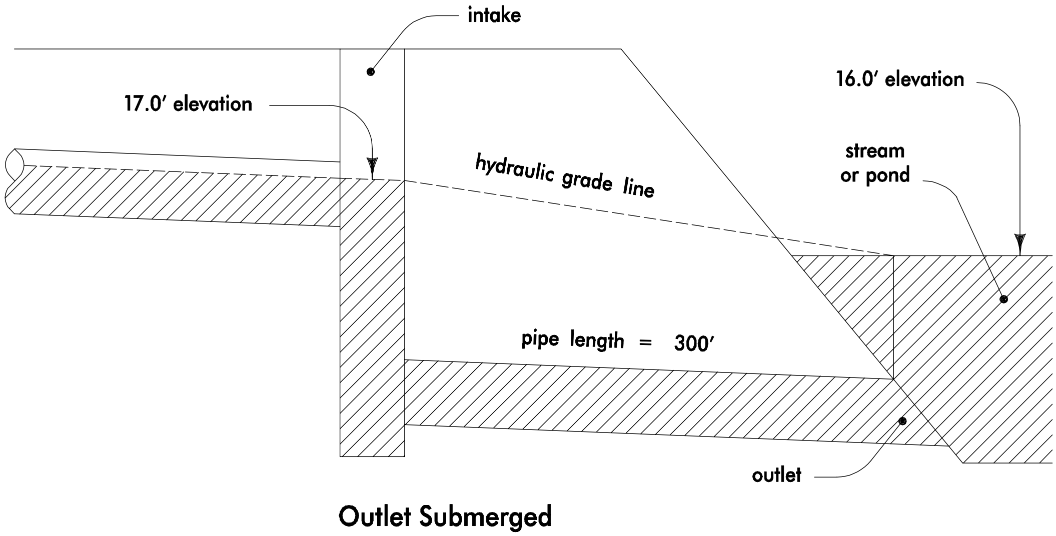

Figure 9: Storm sewer pipe with outlet submerged (Sample Problem 2).

The same procedure would be used with metric units.

Sample Problem for Major Storm Check

Try a 100-year storm check on the sample problem used earlier. In this example, all the water that bypasses Intakes 1, 2, and 3 will run downhill to the sag at Station 8+00 where Intake 4 is located. The critical point is therefore Station 8+00.

Step 1 in the check is to calculate Q for a 100-year storm at P-4 (Columns 18–25 on the design worksheet). Columns 18–23 are not changed by assuming this different design storm.

Column 24: Calculate intensity (I) as shown in Section 4A-4. Using a recurrence interval of 100 years and a storm duration (T_c) of 10.9 minutes, I = 9.2 in./hr.

Column 25: Q = CIA = 1.06 × 9.2 = 9.8 cfs.

Since 9.8 cfs is greater than the capacity (Column 27) of 7.5 cfs, we have pressure flow.

Figure 4 shows that it will take a 0.80% slope to carry 9.8 cfs. To calculate the height of water in Intake 4, take the flow line out (Column 15) and add the diameter of the pipe plus the length (Column 11) times the slope (0.80%):

$$182.40+1.50+(100\text{x}0.80) = 184.70$$

Since 184.70 is less than 187.78 (Column 4 - form grade of Intake 4), Intake 4 will not overflow. P-4 will handle the 100-year storm if the outlet is adequate.

Step 2 is to check the inlet capacity of Intake 4. Figure 9 in Section 4A-6 shows that water must be 0.44 feet deep to handle 9.8 cfs. Since the maximum allowable depth of water on the pavement is 1.0 foot, Intake 4 can handle all the water in the drainage area.

Step 3 is to check overland flow. Since water has not run over the top of the curb in this example (water depth = 0.4 feet), we do not need to check overland flow.

The same procedure would be used for metric units.